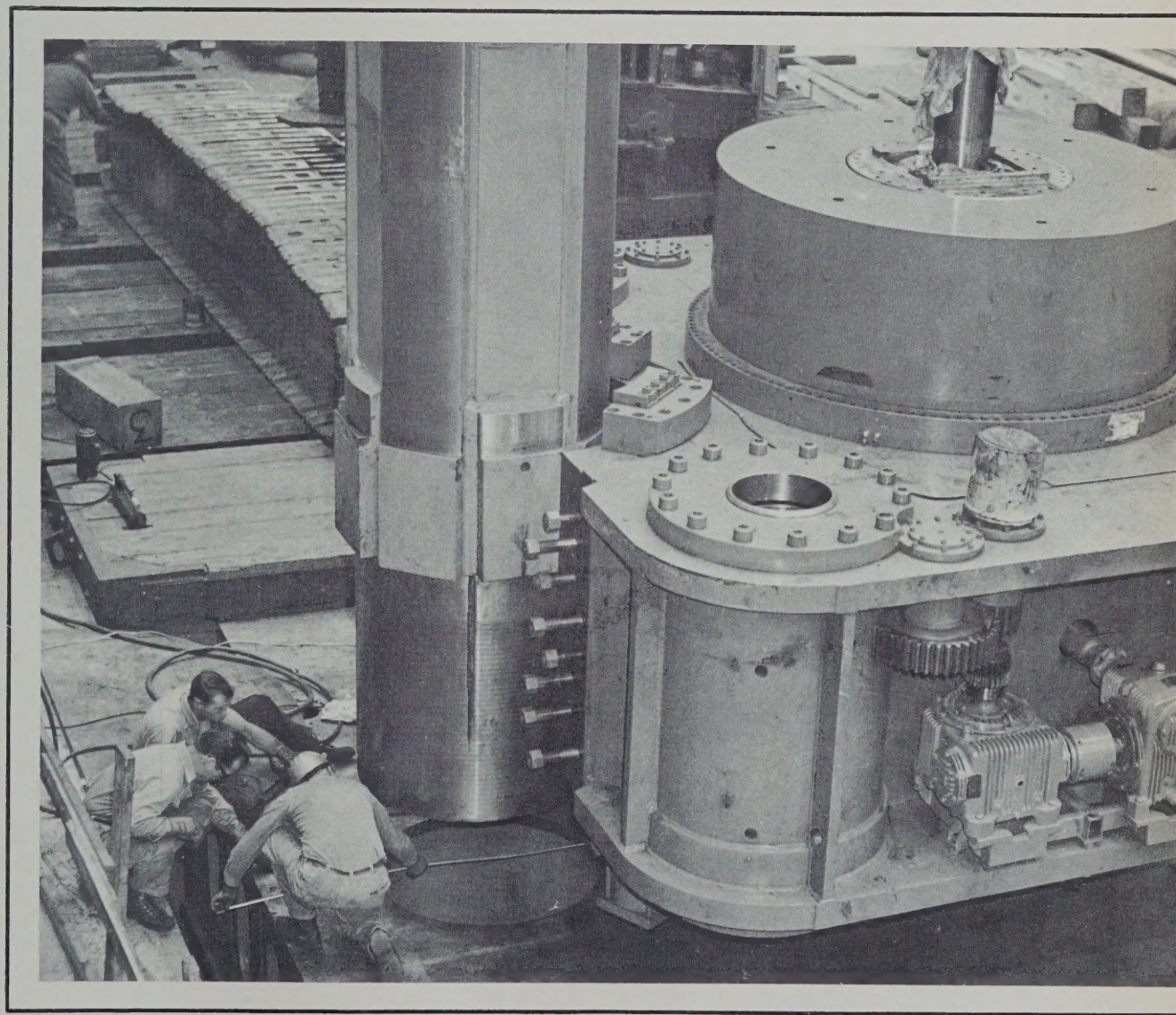
NATIONAL BUREAU OF STANDARDS July 1966

Technical News Bulletin



U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Technical News Bulletin

JULY 1966/VOL. 50, NO. 7/ISSUED MONTHLY

U.S. DEPARTMENT OF COMMERCE
John T. Connor, Secretary

NATIONAL BUREAU OF STANDARDS
A. V. Astin, Director

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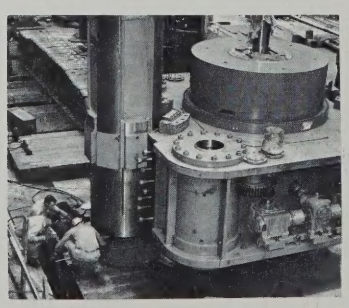

COVER

A 12 million-lb capacity testing machine, believed to be the world's largest, is being installed at NBS. Workers are checking the clearance between the support column being placed and the sensitive crosshead to assure vertical alinement of the column.

Prepared by the NBS Office of Technical Information and Publications
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The National Bureau of Standards serves as a focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. For this purpose, the Bureau is organized into three institutes—
- The Institute for Basic Standards
- The Institute for Materials Research
- The Institute for Applied Technology

The TECHNICAL NEWS BULLETIN is published to keep science and industry informed regarding the technical programs, accomplishments, and activities of all three institutes.

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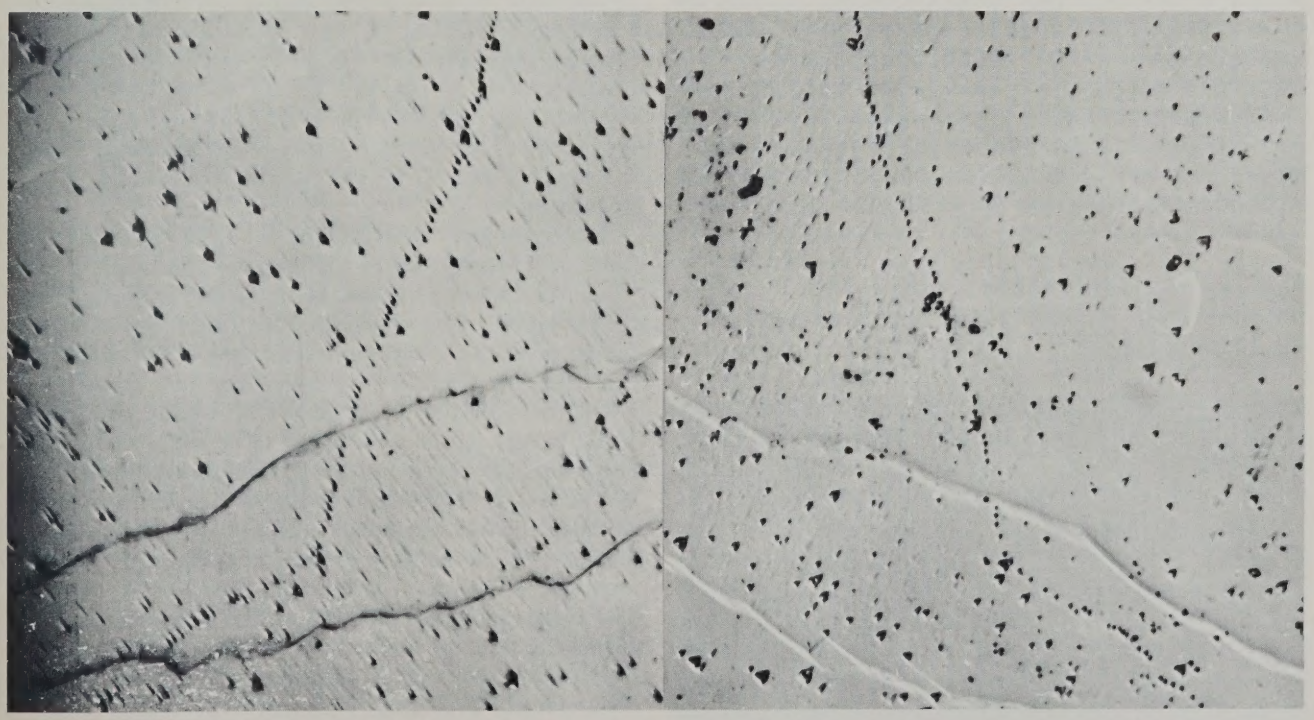
ETCHING TECHNIQUE

reveals dislocations in chromium sesquioxide crystals

An etching technique for revealing dislocations in single crystals of chromium sesquioxide (Cr_2O_3) has recently been developed at the NBS Institute for Materials Research.[1] W. S. Brower and E. N. Farabaugh, of the Institute's crystal chemistry laboratories, perfected the procedure, in work supported in part by the Atomic Energy Commission, for use in studies of high-temperature crystal growth techniques and defects. The method forms many similar etch pits on the surface of a crystal, apparently at dislocations. Scientists developing improved crystalline materials will use this phenomenon in evaluat-

continued on page 115

Microphotographs of facing crystal surfaces produced by cleavage show many etch pits occurring in rows which form patterns that are paired on the two matching surfaces. Analysis of pit location, orientation, and density indicates that the lines formed by the etch pits mark crystalline dislocations.



Range of Glass Viscosity Measurements Extended

Boron Trioxide Viscosity Measured

The accuracy of glass viscosity measurements in the range from 10^7 to 10^{10} poises has been significantly improved in a recent study at the NBS Institute for Materials Research. As a result of this work, glass viscosities can now be measured to high accuracy over the entire range from 1 to 10^{10} poises.

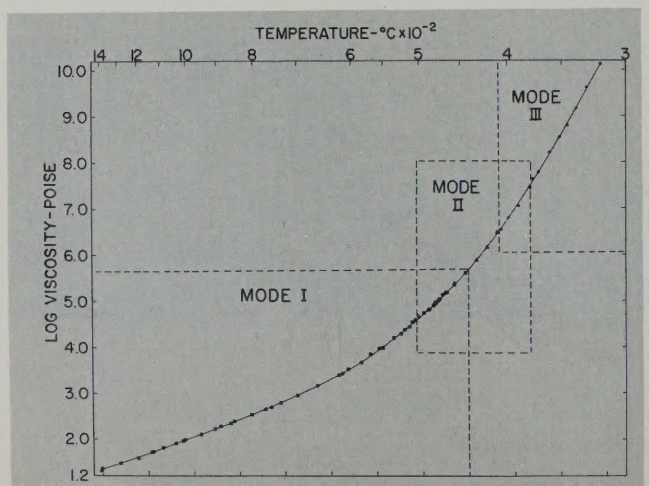
In this study,[1] A. Napolitano, P. B. Macedo, and E. G. Hawkins were able to extend the useful range of the high-temperature rotating-cylinder viscometer into the 10^7 to 10^{10} P region. The viscometer thus replaces less accurate methods previously used in that region.

In conjunction with this work, the viscosity of dehydrated boron trioxide (B_2O_3) glass was measured from 318 to 1403 °C, and its density was determined from 411 to 1400 °C.[2] These measurements were part of a continuing program at NBS to measure the physical properties of standard and high-purity glasses. Data obtained for this high-purity, single-component glass should prove useful to those engaged in fundamental research in the glass industry.

Wide-Range Rotating Cylinder Viscometer

The use of rotating cylinder viscometers has become over the years a standard method of measuring viscosities of glasses at high temperature. This type of viscometer usually consists of a cup (outer cylinder), in which the molten glass is placed, and a spindle (inner cylinder) suspended in the viscous liquid by a torsional fiber. The cup can be rotated at a constant angular velocity. The torsional suspension fiber provides an elastic torque proportional to the angle of deflection. The suspension assembly also contains an electromagnetic coil which provides a magnetic torque to the spindle proportional to the applied current.

Viscosity plotted against temperature for the boron trioxide shows the overlapping of modes I and II and of modes II and III, in which smooth transition occurs and the results agree within the experimental error.



Three Modes of Operation

This viscometer has been operated previously [3] in two modes that permitted measurements of glass viscosities from 1 to 10^7 P. In this study, a third mode was devised to extend the viscometer's range from 10^7 P, its previous upper limit, to 10^9 P, the lower limit of the fiber elongation method. Like the first two modes, this mode is also based on the viscometer's general equation of motion. In the equation, the sum of the inertia of the moving part, the viscous drag on the spindle, and the elastic torque equals the magnetic torque applied to the system.

In the first mode, the cup is rotated at a constant angular velocity, while the torque necessary to keep the spindle at rest is measured electromagnetically. Viscosity measurements taken in this mode are accurate from very low viscosities up to about 3×10^5 poises.

The second mode uses an aperiodic or decay method. The spindle is rotated from its equilibrium position to which it returns under the torque of the suspension fiber. As this system acts as an over-damped harmonic oscillator, the spindle returns with an exponentially decaying angular velocity. The time intervals required for angles to decay to one-tenth their original values are measured. With proper suspension selection, measurements may be made in this mode between 5×10^4 and 4×10^7 poises.

Although the third or "driving" mode was devised to measure viscosities between 10^7 P and 10^9 P, its useful range is from 10^6 to 10^{10} P. In the driving mode, a known torque is applied to the spindle while the cup is held at rest. By use of a highly sensitive optical system, the angular velocity of the spindle is measured to give viscosity.

The viscometer was calibrated at 25 °C with NBS standard viscosity oils (1 to 500 poises) in mode 1. By using the calibration constant obtained for mode 1 and the geometry of the apparatus, the calibration constants for the other two modes were calculated. The calibration constants were checked by measuring the viscosities of NBS glass viscosity standards (NBS Nos. 710 and 711). These measurements were found to be within 0.5 percent of the viscosity curves previously established for the standard glasses by the rotating cylinder and fiber elongation methods.[3] This percentage was well within the experimental error of the data, whose standard deviations were 2 percent for modes 1 and 2, and 3 percent for mode 3. The 3-percent standard deviation for mode 3 is considerably better than the 8-percent standard deviation obtained for the fiber elongation method in the region in which the two methods overlap (10^9 to 10^{10} P).

Viscosity and Density of Boron Trioxide

The first glass for which viscosity measurements were made over the entire range of 1 to 10^{10} was dehydrated boron trioxide glass. This single-component, high-purity glass was prepared from reagent boric acid. Placed in platinum containers, the oxide was melted in a small laboratory furnace at 1300 to 1400 °C with considerable care to avoid contamination. After superficial refining at 1300 °C, the melt was dehydrated by bubbling a "super dry nitrogen gas" (containing less than 7 ppm of water) through it for 16 hours. Glass samples were transferred in platinum crucibles from the furnace to the viscometer without cooling below 300 °C.

As the three modes overlap, there were no gaps throughout the range of 10^1 to 10^{10} P. The accuracy of the measurements was ±2 percent above 700 °C (3×10^5 P) and ±4 percent below this temperature. In the overlapping regions, smooth transitions occurred between adjacent modes and the results agree within the experimental error.

The density of B_2O_3 was measured from 411 to 1400 °C by Archimedes' principle using a restrained platinum sphere. When the measured values of density were plotted against temperature, the data showed that the volume expansion coefficient depends upon the temperature. Over the temperature range measured, this coefficient changed from 3.35×10^{-4}/°C to 3.34×10^{-5}/°C. Also, in the liquid phase between 1200 and 1400 °C, the expansion coefficient was smaller than that in the glass phase (5.50×10^{-5}/°C).[4]

[1] For further details, see **A wide range (up to 10^{10} P) rotating cylinder viscometer**, by A. Napolitano, P. B. Macedo, and E. G. Hawkins. J. Res. NBS **69A** (Phys. & Chem.), No. 5, 449–455 (1965).

[2] **Viscosity and density of boron trioxide**, by A. Napolitano, P. B. Macedo, and E. G. Hawkins, Jrl. Amer. Ceram. Soc., **48**, No. 12, 613–616 (Dec. 1965).

[3] **Viscosity standard sample of glass**, NBS Tech. News Bull. **46**, 175 (1962). **Viscosity of a standard soda-lime-silica glass**, by A. Napolitano and E. G. Hawkins, J. Res. NBS **68A** (Phys. & Chem.), No. 5, 439–448 (1964). **New glass viscosity standard**, NBS Tech. News Bull. **49**, 43 (1965). Also, **Standard Reference Materials: Viscosity of a Lead-Silica Glass**, by A. Napolitano and E. G. Hawkins, NBS Misc. Publ. 260–11 (in press).

[4] **Relation between free volume and elastic moduli in boron trioxide**, by P. B. Macedo, W. Capps, B. O'Meora and T. A. Litovitz. J. Chem. Phys. (in press).

COMPARATOR FOR VOLTAGE TRANSFORMER CALIBRATIONS

Simplified Circuit Built of a Few Available Components

When standardizing laboratories and public utilities want to determine the ratio and phase angle of a voltage transformer, the technique most often used is comparison with a "standard" transformer. A comparator of new design for doing this frequently needed calibration task was recently constructed by the Bureau.[1] It makes use of a resistance-capacitance network to give the angle between the voltage phasors and of an inductive voltage divider whose dial readings give the relative magnitudes of the ratios. The comparator was developed by Wilbur C. Sze of the NBS Institute for Basic Standards in work supported in part by the Bureau of Naval Weapons.

Overall accuracies within 0.001 percent in relative ratio measurements and 0.2 minute in phase angle are easily attained at frequencies from 60 to 1000 Hz with circuits of this type. The NBS instrument was specially designed for use at 60 Hz; but because the circuit is a simple hookup of components readily available in most electrical measurements laboratories, a comparator adapted to another frequency can quickly be assembled.

The flexibility of the circuit is such that only a few ranges of standard transformers are required. Fractional ratios between the "standard" and "test" transformers anywhere in the range from 1/1 to 1/4 may be measured as readily as those near unity.

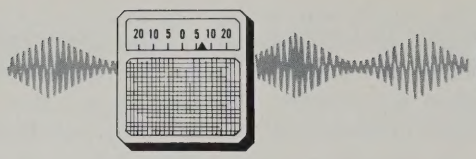
At balance, the R–C network introduces a quadrature voltage equal, but of opposite polarity, to the voltage resulting from the difference in phase between secondary voltages of the "standard" and "test" transformers. The in-phase voltage balance is achieved by adjusting the ratio of the inductive voltage divider.

A junction box provides the necessary interconnections between the transformers and comparator components. It contains a specially shielded transformer for impedance matching and isolation of the detector from the measurement circuit. The shielded transformer consists of a high-permeability toroidal core, a 700-turn inner primary winding, two electrostatic shields, a 3500-turn outer secondary winding, and an overall Mumetal case. The toroidal design minimizes magnetic pickup from stray fields. The toggle switch is for reversing the relative phase angle; a plus sign indicates that the voltage phasor of the "test" transformer leads that of the "standard."

The inductive voltage divider should be a six-decade unit (or one with five decades and a resistive divider) designed for optimum performance at the desired test frequency. C of the R–C network should be a high grade capacitor containing a 10×1 nF decade with a dissipation factor of less than 0.0003. R should be a 0–11 kilohm unit of at least four decades with small residual reactance. Care should be taken to insure that all exposed metal parts of R are properly insulated to prevent electrical shock to the operator.[2]

[1] **Comparators for voltage transformer calibrations at NBS**, by Wilbur C. Sze, J. Res. NBS **69C** (Engr. and Instr.), No. 4, pp. 257–263 (Oct.–Dec. 1965).

[2] Further details regarding this comparison circuit and reprints of the paper cited can be obtained from the High Voltage Section, Electricity Division, National Bureau of Standards, Washington, D.C., 20234.



STANDARDS AND CALIBRATION

LINE-STANDARD FEE REDUCED

A sharp reduction, from $33.00 to $3.00, has been made in the fee for comparing the nominally equal subintervals of a line standard with a wavelength standard of length. The fee applies specifically to item 202.402c of the NBS fee schedules.[1]

The notable drop in cost was made possible by the development at NBS of an instrument which is a form of Michelson interferometer using a laser light source and having an automatic, reversible, electronic fringe counter with computer-adapted readout. A technical account of the device has already appeared,[2] and a descriptive article is being prepared for publication in a subsequent issue of this *Bulletin.*

[1] These schedules are gathered together in NBS Misc. Pub. 250, Calibration and test services of the National Bureau of Standards, 1965 edition. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, for $1.00.

[2] An automatic fringe counting interferometer for use in the calibration of line scales, by H. D. Cook and L. A. Marzetta, J. Res. NBS 65C, 129 (1961).

NEW PROGRAMMERS FOR WWV

Another step in the relocation of NBS radio station WWV from Greenbelt, Md., to Fort Collins, Colo., has been taken with the award of a contract to Electronic Engineering Co. for three time-code generator-programmers and a time-code comparator plus associated controls and standby power equipment. The Santa Ana, Calif., company has agreed to deliver the equipment to the NBS Boulder Laboratories before June 15.

The time-code generator-programmers develop the signal broadcast by WWV for six of its eight services:

Standard audio frequencies: 600 and 440 Hz

Standard musical pitch: 440 Hz (A above middle C)

Time signals: in mountain standard time after the move to Fort Collins. (They are now in eastern standard time.)

Geophysical alerts: the alerts signal days on which outstanding solar or geophysical events occur.

Universal time (UT2) difference: amount by which broadcast time should be altered to give astronomical time, which is known only to within 2 or 3 milliseconds.

Propagation Forecasts: Condition of ionosphere and prediction of radio quality for the next 6 hours.

The other two services—standard radio frequencies and time intervals—are derived more directly from the national standards.

The time-code comparator automatically checks the output of the three generator-programmers and signals departures by any one generator of more than five millionths of a second from any of the others. It also signals other related types of breakdown so that the engineers on duty can immediately take corrective action.

On delivery to Boulder, the equipment will be interconnected with other control units and checked out before being installed in the new transmitter building. The latter has been designed by Ditzen-Mueller and Associates of Boulder and is expected to be completed later this summer, with the equipment installed and ready to begin operation.

For an earlier report on the removal to Fort Collins, see the NBS Technical News Bulletin **49,** No. 12, 215 (December 1965). The various services provided by WWV and the other NBS stations are described in NBS Miscellaneous Publication 236, *NBS Standard Frequency and Time Services,* 1966 Edition; for sale at 15 cents per copy by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.

EFFECTIVE EFFICIENCY OF COAXIAL BOLOMETER UNITS AT 9 GHz

The Radio Standards Laboratory (Boulder, Colo.) of the NBS Institute for Basic Standards has added a new service for the measurement of effective efficiency of coaxial bolometer units at a frequency of 9 GHz and a power level of 10 mW. The units must be fitted with male Type N connectors and thermistor-type elements of 200-ohm nominal operating resistance. "Effective efficiency" is defined as the ratio of the substituted d-c power in the bolometer unit to the microwave power dissipated within the unit.

INSERT SHEETS UPDATE MISC. PUBL. 250

Additional "Insert Sheets" which describe recent changes in NBS calibration services and fees, and thereby bring up-to-date the 1965 edition of NBS Miscellaneous Publication 250, *Calibration and Test Services of the National Bureau of Standards,* were sent out in May to those on the mailing list for this service. To get on the mailing list, owners of a copy of Misc. Publ. 250 should fill out the postcard that accompanies each copy of the publication and mail it to the Office of Technical Information and Publications, National Bureau of Standards, Washington, D.C., 20234.

U.S. STANDARD FREQUENCY AND TIME BROADCASTS

WWV—2.5, 5.0, 10.0, 15.0, 20.0, and 25.0 MHz
WWVH—2.5, 5.0, 10.0, and 15.0 MHz
WWVB—60 kHz

Radio stations WWV (Greenbelt, Md.) and WWVH (Maui, Hawaii) broadcast signals that are kept in close agreement with the UT2 scale by making step adjustments of 100 ms as necessary. Each pulse indicates that the earth has rotated approximately 15 arcseconds about its axis since the previous one. Adjustments are made at 0000 UT (7:00 p.m., e.s.t.) on the first day of a month. There were no adjustments made on either 1 June or 1 July 1966. The pulses occur at intervals that are longer than one second by 300 parts in 10^{10} due to an offset in carrier frequency coordinated by the Bureau International de l'Heure, Paris, France.

Radio station WWVB (Fort Collins, Colo.) broadcasts seconds pulses derived from the United States Time Standard (USTS) with no offset. Step adjustments of 200 ms are made at 0000 UT on the first day of a month when necessary. NBS directs that such adjustments be made in the scale at intervals to maintain the seconds pulses within about 100 ms of UT2. *There was an adjustment made on 1 June 1966. The seconds pulses emitted from WWVB were retarded 200 ms.* There was no adjustment made on 1 July 1966.

FLOW RATE OF LIQUID HYDROGEN DETERMINED BY NMR TECHNIQUE

In a study at the NBS Institute for Materials Research, scientists are "listening" to faint radio signals, emitted by nuclei in liquid hydrogen, to determine the flow rate of that supercold liquid. This investigation is sponsored by the National Aeronautics and Space Administration, and is under the direction of Charles E. Miller of the Institute's cryogenics laboratory in Boulder, Colo.

The purpose of the investigation is to explore the feasibility using a nuclear magnetic resonance (NMR) technique to measure the flow rate of liquid hydrogen under conditions that are encountered in the fueling of rockets. The advantage of such a method, over conventional ones, is that no electrical or mechanical measuring device comes into contact with the liquid to introduce energy or heat into it. Although this technique has been successfully demonstrated in laboratory tests using experimental equipment, actual field tests are yet to be performed.

The technique is based on the physics of NMR, which had its beginning in 1946. In that year, two scientists, Bloch and Purcell, discovered that most nuclei behave like tiny spinning bar magnets. They also found that such nuclear magnets, when placed in an appropriate direct current magnetic field and simultaneously irradiated by just the right kind of radio frequency magnetic field, reveal their presence by emiting minute radio signals.

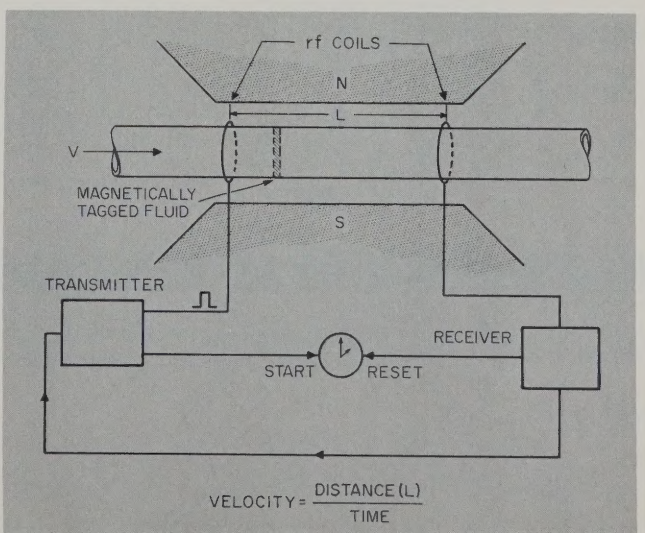
In the Institute's experimental flow rate apparatus, the liquid hydrogen is subjected to a direct current magnetic field to rearrange the magnetic nuclei. This is necessary because, under ordinary circumstances, the nuclear magnets spin or precess in random orientation, with the result that all appreciable magnetic effect is canceled out. In a d-c magnetic field, however, all the magnetic nuclei are alined along the direction of the field, where they spin together to produce a measurable quantity of nuclear magnetism.

Test equipment for measuring the velocity or flow rate of liquid hydrogen, by the nuclear magnetic resonance technique, makes use of two rf coils wound around the hydrogen pipeline, which is located in the magnetic field. The upstream coil serves as a transmitter, while the downstream coil functions as a receiver. When the upstream coil is momentarily energized, radio waves of exactly the same frequency as the precessing nuclei magnetically "tag" a segment of the fluid. The magnetically tagged fluid is then detected by the downstream receiver coil. A measure of the time taken for the fluid to travel the known distance between the two coils is a measure of the fluid velocity.

To date, the NBS program has consisted of extensive basic research to accurately determine the nuclear magnetic properties of liquid hydrogen, the determination of feasible techniques, and the construction of experimental equipment necessary to measure fluid velocity.

The next phase of the program will be to use the knowledge of laboratory methods to construct field equipment needed for actual testing at NASA's rocket sites, where liquid hydrogen is used extensively as a propellant in many advanced U.S. missiles.

The d–c magnetic field alines the fluid's magnetic nuclei in the direction of flow. The transmitter coil "tags" a segment of the fluid. The receiver coil detects the tagged fluid thereby permitting the travel time to be measured.



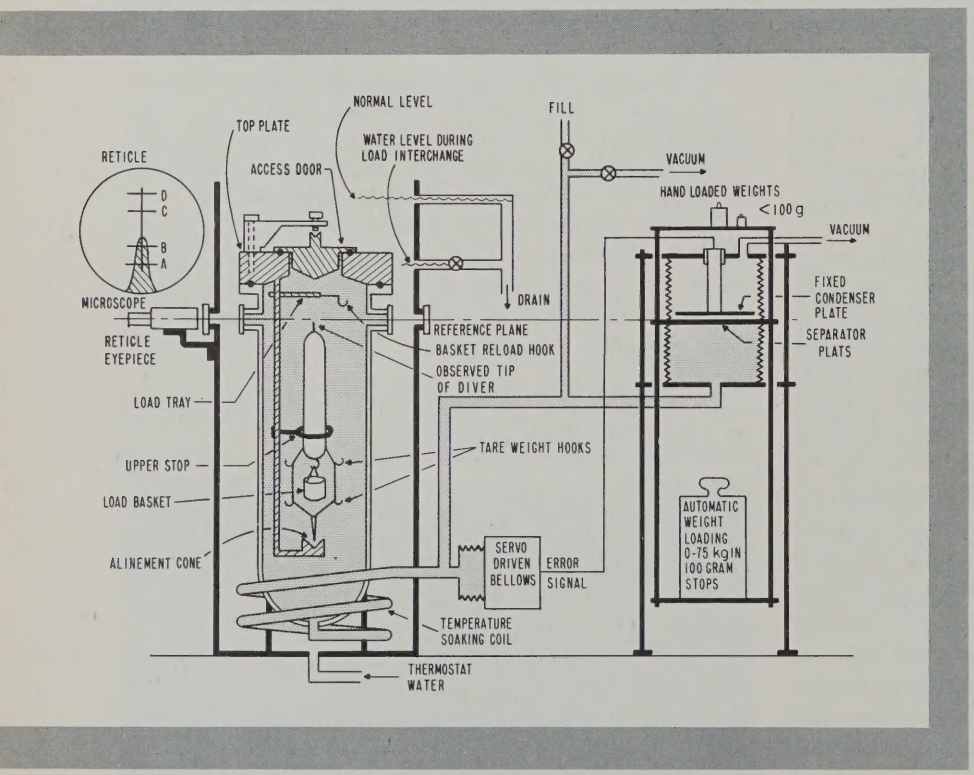
Cartesian Diver Gives Precise Technique for Density Comparisons

The Cartesian diver, a device often used to demonstrate water buoyancy in the classroom, has been employed to increase the precision of hydrostatic weight comparisons by one to two orders of magnitude. The diver was adapted to this purpose by H. A. Bowman and R. M. Schoonover of the NBS Institute for Basic Standards. Their work [1] now provides a useful technique for precisely comparing the densities of extremely small specimens. Previously shortcomings in classical hydrostatic weighing have limited the precision in measuring such differences.

Density comparisons have widespread technical applications. By comparing densities, investigators may detect changes in nominally identical objects that have been exposed to various conditions such as high temperature. It is often necessary to evaluate density differences among chemically identical materials that have different physical properties, such as hard-drawn and annealed wire. Also, comparisons of densities in samples taken from different parts of an object help to provide an evaluation of its homogeneity.

The density of an irregularly shaped object is usually found by a combination of air and water weighing in which the apparent mass of the object is determined in both media. The density is then calculated by solution of an equation relating the mass, volume, and density of the displaced air and water.

A principal disadvantage of this method is the uncertainty in water weighing that is caused by imperfect knowledge of water density, surface tension, turbulence and convection currents. A variability of 10 micrograms for a 250-milligram object may frequently result in an unsatisfactory measurement. The NBS-constructed apparatus is operated at 4 °C. At this temperature thermal convection currents are at a minimum. The effect of surface tension is eliminated because the diver is operated completely submerged in water at all times.



The Cartesian diver in its chamber (left) rises or falls when pressure is decreased or increased by the two-bellows pressure system (right).

Diver Principle

Basically, the diver is a closed-surface, hollow tube about 12 cm long.

It is constructed of fused quartz with very thin walls so that, with respect to water, it is quite compressible. Hooks and guides are attached to facilitate loading and manipulation.

When water pressure is increased the diver body is compressed and the consequent loss of buoyancy causes it to fall. Conversely, when the pressure is decreased the diver will expand and rise. Because of the pressure gradient in water due to gravity, the diver moves into an area of lower pressure as it rises. This causes an additional expansion of the body so that buoyancy is increased and the diver accelerates upward. The converse is true when the diver falls. Thus, it is impossible for the diver to find a level of stable equilibrium. Neverthless, there is a pressure which results in the loaded diver having a density precisely equal to that of the displaced water. This pressure, called equilibrium pressure, can be adequately determined from an average of the two pressure that cause the diver to move upward and downward, in equal intervals of time, across a range extending an equal distance above and below a reference plane.

Pressure System

Pressure is controlled in the system by a modification of the NBS two-bellows barostat, in which one bellows is mounted above the other. The upper bellows is evacuated, and the lower bellows is filled with water and connected to the diver chamber. The upper end of the upper bellows and the lower end of the bottom bellows are rigidly attached to the frame. The two bellows are mechanically connected by a freely floating separator plate. This plate is electrically connected as the moving plate of a two-plate variable capacitor, with the fixed plate rigidly attached above it.

The separator plate is allowed to move between stops through a distance of 0.025 cm. When weight is loaded on the separator plate by a semi-automatic device, the plate's movement causes a change in electrical capacitance. The capacitance between the fixed and moving plate is used as an error signal for a system which provides servo power to a motor-driven bellows connected in the hydraulic system. Pressure is increased or decreased to drive the separator plate in such a direction that it is maintained at the midpoint of its allowed travel distance, regardless of loaded weight. Thus, the two-bellows assembly is used as an error signal generator and actual pressure changes are made by the servo-driven bellows.

Determination of Apparent Mass

Changes in the equilibrium pressure reflect changes in the apparent mass of the loaded diver with load changes. Two standards of known apparent mass serve to calibrate the pressure scale in terms of apparent mass of the load, so that the equilibrium pressure associated with an unknown load can be used as a measure of its apparent mass. The nonlinearity of the system has been carefully measured and is accounted for in the calculations. Independent measurements on apparent mass in water are reproducible to a standard deviation of 0.1 to 0.2 μg with loads up to 10 g.

The diver system as described is used primarily as a density comparator. However, it can also be used to determine absolute density. In this case, however, it is only as accurate as the density value assigned to the standards used in comparisons. NBS is now planning to develop a more accurate density standard to realize fully the capabilities of the diver system.

[1] Cartesian diver as a density comparator, by H. A. Bowman and R. M. Schoonover, J. Res. NBS 69C (Engr. and Instr.), p. 217 (July–Sept. 1965).

LIST OF ERRATA FOR HANDBOOK OF MATHEMATICAL FUNCTIONS

Owners of any of the first three printings of the *Handbook of Mathematical Functions* should take note that a cumulative list of errata has been prepared and that they may obtain a copy of it by submitting a request to the Publications Section, Office of Technical Information and Publications, National Bureau of Standards, Washington, D.C., 20234. Requests accompanied by a stamped, self-addressed envelope (business size) will be assured of more prompt service.

Issued as a small pamphlet, the list gives the customary information concerning location and identification of the error and how it is to be corrected. In addition, the printing (1, 2, 3, or 4) in which the error was first corrected is also given, so that the user is not tempted to correct an error that has already been eliminated from his printing. As a further precaution against this, asterisks have been put at those places in subsequent printings where corrections have been made.

The first printing can be identified by the dateline near the bottom of the title page, "Issued June 1964"; the others have "Second Printing, Nov. 1964, with corrections"; "Third Printing, March 1965, with corrections"; and "Fourth Printing, issued Dec. 1965, with corrections."

Full title of the volume is: *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables.* It was edited by M. Abramowitz and I. A. Stegun, and is number 55 in the NBS Applied Mathematics Series. Copies may be purchased at $6.50 each from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.

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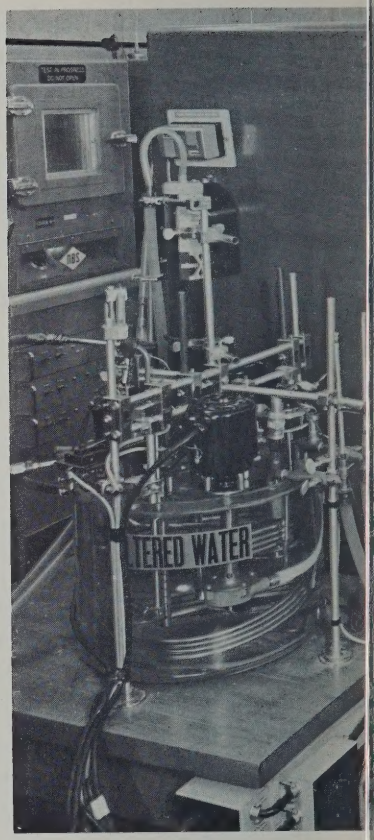
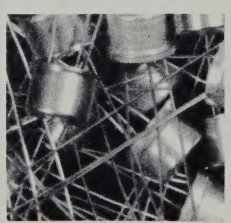
TRANSISTOR RELIABILITY: Which ones should be used?



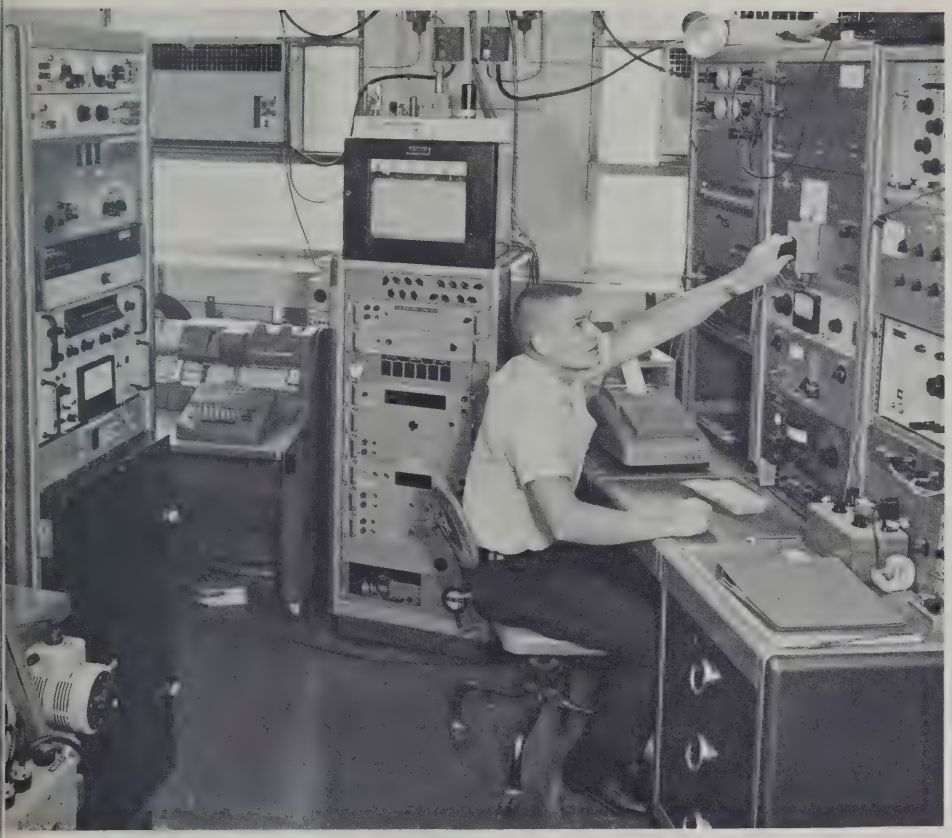
NBS scientist develops technique for predicting failure from changes in leakage current



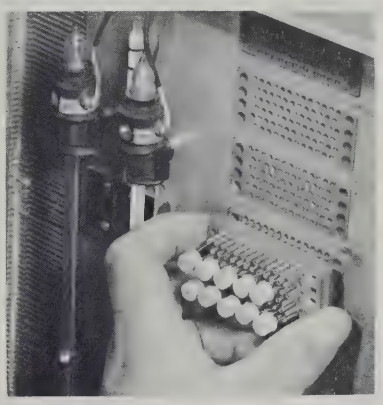
Failures among certain transistor types can be predicted from measurements of leakage current before they are placed in service, according to a study recently completed at the NBS Institute for Applied Technology.[1] The application of screening procedures developed in this study to germanium-alloy transistors may increase the reliability of transistorized equipment, including weapon systems, communications systems, and space vehicle instrumentation.

The NBS study, sponsored by the Department of the Navy, was carried out over a period of 3 years by George T. Conrad, Jr., and Donald C. Shook, using the technique of accelerated aging by exposure to moderately elevated temperatures. They found that measurements of performance before and after 6 weeks of this aging enabled them to separate the transistors tested into two groups: those likely to fail during the first several years of service and those unlikely to fail.

The transistor failure prediction study was comprised of two experiments, the first a statistical evaluation of changes in parameters occurring during accelerated aging



Donald Shook adjusts equipment used to test transistors to find early changes that identify failure-prone specimens. The equipment (from left) is an aging oven (rear), water temperature-stabilizing and circulating apparatus (foreground), thermostatted test chamber and control circuitry, keypunch, recorder, and control console.



Above, inserting transistor leads into a plug for a long-term testing program. Below, the plug carrying ten transistors is inserted into a receptacle in a chamber which is thermostatted at 25 ±0.01 °C.

simulating years of actual operation. Early changes in leakage current parameters were found to follow the same pattern for all transistors that would have failed within several years of normal use. A screening procedure was developed from these data and its effectiveness verified in a second experiment which also tested the usefulness of additional variations in aging conditions.

First Experiment

In the first experiment, groups of 40 2N396 germanium alloy transistors, which had met stringent military requirements, were subjected to an initial series of measurements and then each group was placed in a temperature-controlled chamber. Ambient temperatures and bias powers were selected to provide junction temperatures of 25, 55, 100, 145, and 200 °C. The transistors were removed for repeated measurement runs after 340 hours of aging and returned to the ovens. This was again done at 1,000 hours, 4,700 hours, and at intervals up to 20 kilohours of aging.

Transistor performance was evaluated on the basis of measurements of the following d-c parameters: emitter-base current (IEBO) at −2 and −10 V; collector-base current (ICBO) at −2 and −10 V; collector-emitter current at −10 V with base grounded (ICES), grounded through a 10-kΩ resistor (ICER), and open (ICEO); and normal and inverse current transfer ratios for the common-base configuration at 10 mA and −5 V.

Measurement Procedure

The procedure for measuring transistor parameters was designed to minimize the effects of variation in measurement conditions and to make use of automatic datalogging equipment. The latter resulted in fast, accurate, and convenient recording and data processing by computer. Damage due to handling was minimized by mounting the specimens, in groups of 10, on multicontact plugs; the individual specimens were not manipulated during the remainder of the experiment. Finally, the temperature of the room in which the experiment was performed was

continued

maintained at 25 °C and that of the chamber in which measurements were made was regulated at 25±0.01 °C.

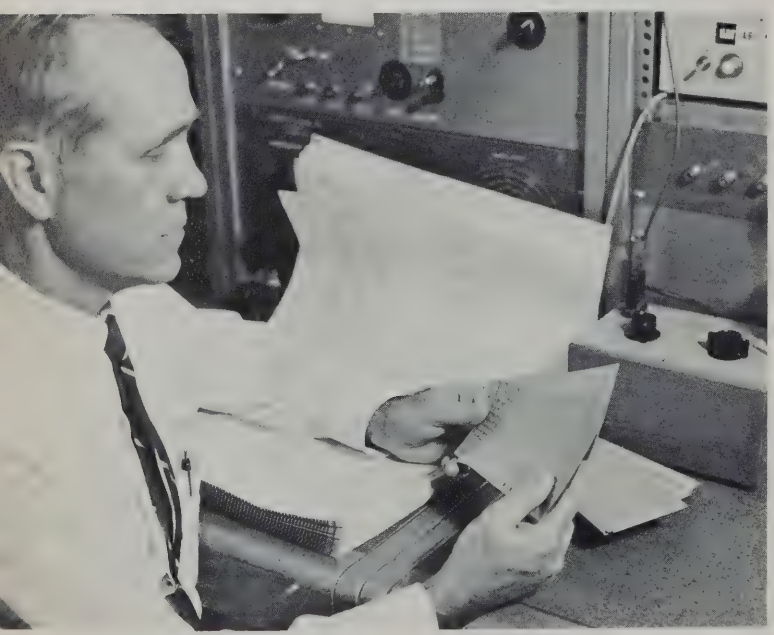
Some measurement variation could and did occur, despite all precautions; some specimens consistently gave fluctuating measurements. These specimens were identified in the measurement routine in which replicate measurements were made of each parameter. The entire series of parameters was measured in the morning, after the specimens had stabilized for a day at 25 °C, and repeated in the afternoon; the same measurement routine was repeated following 6 more days of stabilization at 25 °C. Replicate readings were immediately compared by a computer and parameters differing by more than 2 percent were printed out for inspection. Measurements from specimens previously known to fluctuate were accepted, while those from previously stable specimens were repeated for further comparison.

Experimental Findings

Analysis of the measurements first showed that deterioration at 25 and 55 °C was too slight, and that at 145 °C and above too great to shed much light on the meaningfulness of small, early changes. For this reason data from only the four groups of transistors aged at 100 °C were analyzed further.

The aging was found to be accompanied by a gradual dispersion in values of the parameters and by ten failures during the 20,000-hour aging period. Two specimens failed because of avalanche conduction, six because of too great a leakage current, and the remaining two catastrophically, one possibly because of previous physical damage. The specimens failing came from all four aging conditions represented: zero bias, −24 V reverse collector bias, and 3 mW power dissipation (all for 100 °C ambient); and the fourth, 100 °C junction temperature from the combination of 70 °C ambient and 120 mW power dissipation.

George T. Conrad, Jr., examines punched cards on which measurements of operational parameters of transistors are encoded and recorded automatically in a form acceptable for input to computers and can be obtained as a printout (background).



Data Analysis

Early increases in leakage current, among the parameters tested, were found to be consistently associated with the first transistors failing. The first 3 failures among the 160 specimens would be expected to occur within about 4 years of normal use, based on the approximation that the rate of deterioration doubles for every 10 °C increase in junction temperature. Normal operation is taken to be 55 °C. The changes in leakage current during 1,000 hours of accelerated aging—the ratio of the current at 1,000 hours to the initial value—were found to be the best indicator of failure during the first 4 to 10 years of projected actual use. (Furthermore, the change identified which junction would deteriorate more rapidly.)

Second Experiment

A second experiment was performed to test the screening procedure obtained from the first experiment and to evaluate the relative effectiveness of two different methods of maintaining junction temperature. Forty of the same transistor type (2N396) used in the first experiment and 40 R212 transistors from each of two manufacturers, all considered to be high-reliability devices, were used in the second experiment.

Results of the second experiment confirmed earlier findings regarding the usefulness of the leakage current screening procedure.

Conclusions

The best criterion for the transistor types tested appears to be an increase in leakage current beyond an acceptable level after the device is stored 1,000 hr at 100 °C. The leakage-increase factor can be chosen between 1.6 and 2.2, according to the experimental findings.

This experiment also showed that questionable predictions may result from using dissipation of power to help maintain high-junction temperatures. Under such conditions differences in thermal resistance between specimens of different manufacture have been observed to lead to poor failure predictions. This was verified in the experiment by subsequent normal-stress aging and testing.

[1] A transistor screening procedure using leakage current measurements, by G. T. Conrad, Jr., and D. C. Shook, J. Res. NBS 69C (Engineering and Instr.), 319–330 (Oct.–Dec. 1965).

ETCHING TECHNIQUE *continued*

ing samples of Cr_2O_3 to identify desirable production techniques.

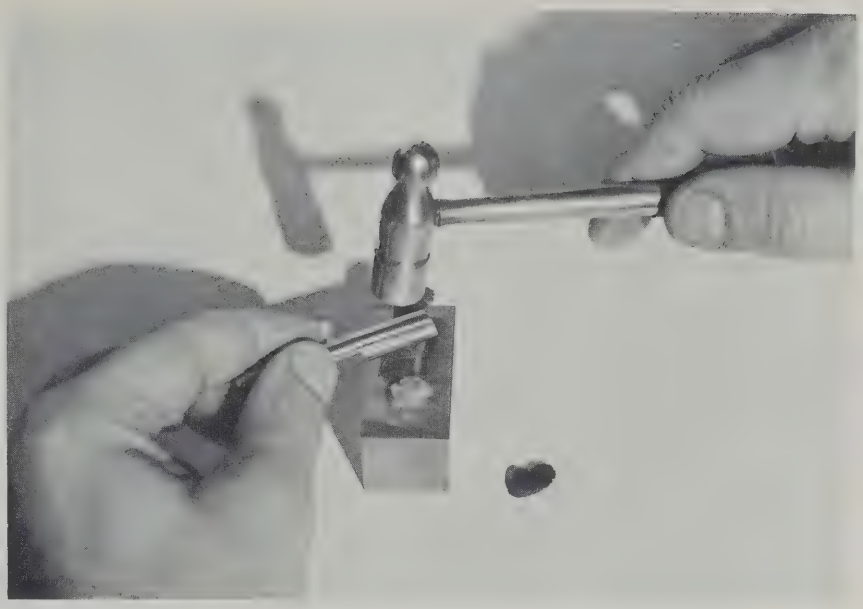
Correctly characterizing samples of crystalline materials requires knowledge of the number and kind of defects, such as dislocations, low-angle boundaries, and voids or inclusions. A number of inorganic crystals can be evaluated by etch techniques, but one successful technique is not necessarily transferable to a different material. Such a technique has been needed for chromium sesquioxide as part of a larger program of crystal growth and characterization.

Etching Technique

An etching method was developed by Messrs. Brower and Farabaugh for studying dislocations in chromium sesquioxide crystals grown at the Institute by S. F. Holley. The crystals had been grown by means of the Verneuil technique, in which chromium sesquioxide powder is drifted down inside a conical, downward-directed flame. The flame is fed by oxygen and hydrogen, delivered from concentric orifices in a specially designed burner. Some of the powder melted by the heat is deposited beneath the flame on a molten surface which is withdrawn as it forms. The crystal grows in the form of a cylinder having a diameter of ½ to 1 cm.

Samples for etching were obtained from the boule, or rod of crystalline material, by cleaving (splitting off) disk-shaped pieces or cutting them off with a diamond saw. Specimens cut from the boule were mechanically polished before etching, while the cleaved ones were etched without other preparatory treatment.

The specimens were etched by immersion in sodium hydroxide, maintained in fusion at a temperature of 550 °C. They were removed after 5–7 minutes of this treatment and, after cooling, were cleaned with water. The flat surfaces of the specimens were then examined under the metallographic microscope, using oblique illumination; they were found to contain many pits.



Samples of crystalline material are obtained from a boule by cleaving (shown) or by cutting. If the chisel is alined parallel to a crystal plane, a sharp blow of the hammer will split off a disk-shaped sample.

Etched Pits

The pits on the surface of each specimen were identical in shape, but different among the crystallographic planes of the specimen. The pits were seen as equilateral triangles on the {0001}, or basal, surface of the crystal. On the {1011} plane, on the other hand, the pits were seen to be five-sided. In all cases, each side of each pit was parallel to one side of each of the other pits on the same plane surface.

A study of the opposing surfaces exposed by cleaving revealed that some of the etch pits on these surfaces are in rows and some are randomly distributed. The rows form patterns that are mirror images of each other on the matched cleavage faces, as do the randomly distributed pits, suggesting that these etch pits had formed along dislocations, as they do in some other materials. The overall density of the pits in samples was observed to be of the order of $5 \times 10^5/cm^2$, which is a reasonable figure for pits formed on dislocations.

The orientation of the dislocation can be qualitatively determined by the position of the apex of the etch pit. When the apex of the pit is located in the center of the pit outline on the basal plane, then it indicates that the pits have been formed on dislocations normal to that plane.

It is then reasonable to conclude that the rows of pits are formed on pure tilt boundaries of crystalline material displaced to form a dislocation. In addition, the crystal samples were analyzed in the light of a previously observed pattern of pit formation on dislocations in other material,[2] in which the linear pit density in one boundary is equal to the sum of the densities in the other two boundaries. The pit patterns in chromium sesquioxide analyzed at the Institute satisfy this condition, supporting the view that these patterns of etch pits correspond to crystalline dislocations.

[1] Etch pits in chromic oxide by W. S. Brower and E. N. Farabaugh, J. Appl. Phys. **36**, 1489–1490 (April 1965).

[2] Dislocation etch pits in antimony by J. H. Wernick, J. N. Hobstetter, L. C. Lovell, and D. Dorsi, J. Appl. Phys. **29**, 1013 (July 1958).

CONFERENCE & PUBLICATION *Briefs*

NEUTRON CROSS SECTION TECHNOLOGY

Over 250 persons, including 20 from foreign countries, attended a Conference on Neutron Cross Section Technology which was held in Washington, D.C., March 22–24, 1966. The meeting was sponsored by the American Physical Society, the Atomic Energy Commission, the National Bureau of Standards, and the Technical Group on Reactor Physics of the American Nuclear Society.

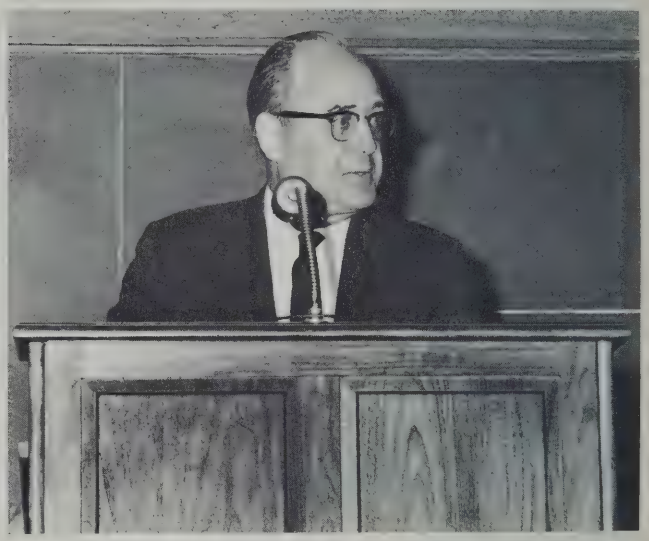
The purpose of this Conference was to present a comprehensive picture of the field of neutron cross section technology to both the measurers and users of neutron cross sections by providing them with the opportunity for an exchange of ideas and information. From this exchange, the users of neutron cross sections gained a better understanding of the problems of neutron cross section measurement and the measurers gained a better understanding of the importance of accurate, detailed data for the solution of practical physics and engineering problems.

One of the highlights of the Conference was the after-dinner speech by Dr. Alvin Weinberg, Director of the Oak Ridge National Laboratory. The title of his talk was "Nuclear Physics and Neutron Cross Section Technology." He suggested that nuclear physicists were underselling the practical applications of this field, and he pointed out the enormous impact that the development of nuclear energy has had on the political, economic, and scientific phases of society. He mentioned, for example, that the development of radioactive tracer techniques had in recent years revolutionized many branches of science and technology.

Fifty-nine papers, including 21 invited papers, were presented at the Conference. These papers, plus 37 papers which were listed in the Conference program but were not given orally, will be published by the Atomic Energy Commission in the proceedings of the Conference. When available, the proceedings can be purchased from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Va., 22151.

WASHINGTON CORROSION DIALOGUE

The National Bureau of Standards, together with the Naval Research Laboratory and the Office of Naval Research, sponsored a scientific symposium on the coupling of Basic and Applied Corrosion Research, March 21 and 22 at NBS. The symposium, the first to be held at the new NBS site in Gaithersburg, Md., was attended by nearly 400 scientists from industry, education, and government. The first day the participants attended meetings at the NBS Washington laboratories, where they were welcomed by Dr. Gordon K. Teal, Director of the NBS Institute for Materials Research. The second day's activities were conducted in the large auditorium at Gaithersburg.



Dr. Gordon K. Teal, Director of the NBS Institute for Materials Research welcomes the participants of the Washington Corrosion Dialogue.

The final session was a panel discussion consisting of (left to right) J. J. Harwood, Ford Motor Co., panel chairman; M. J. Pryor, Olin Mathieson Chemical Corp.; J. E. Draley, Argonne National Laboratory; M. G. Fontana, Ohio State University; and F. L. LaQue, International Nickel Co.

The symposium was designed to bring about a dialogue between workers conducting basic and applied research in the field of aqueous corrosion. A communication problem has existed between these two groups because of diverse points of view and differences in professional goals. The symposium attempted to achieve understanding of the overall problems faced by both groups by presenting widely recognized, representative speakers from both areas and encouraging open discussions among those actively engaged in the aqueous corrosion field.

Speakers for the symposium came from industrial, educational, and governmental institutions throughout the United States, Canada, Belgium, and Great Britain. They discussed topics dealing with new techniques in developing an atomistic basis for aqueous corrosion, new techniques in characterizing the corrosion of engineering alloys, interaction of microstructure and chemistry, stress corrosion and fatigue, the influence of solution chemistry on metallic dissolution, and marine and desalination problems. As a summation, a panel discussion was held on the interaction of basic and applied corrosion research, placing particular emphasis on points brought forth in the technical sessions.

NON-LINEAR EFFECTS IN PLASMAS

Dr. G. Kalman, a visiting fellow at the Joint Institute for Laboratory Astrophysics (JILA), is one of the organizers of a Summer Institute to be held at the University of Paris. JILA is a collaborative effort of the National Bureau of Standards and the University of Colorado.

The Institute on Non-Linear Effects in Plasmas is scheduled for September 5 through September 23 at the Faculté des Sciences d'Orsay, Université de Paris, Orsay, Seine-et-Oise, France, under sponsorship of the NATO Advanced Research Program. It will be on an advanced level, aimed at graduate students and research workers.

According to Dr. Kalman, participation in the institute is free, but the number of participants is limited. Each is expected to pay for lodging and board, but the organizing committee will help to secure accommodations on the campus or in Paris. Some grants may be available to cover travel expense for U.S. citizens.

Persons interested should write Dr. Kalman, JILA, University of Colorado, Boulder, Colo., for further information. Or they may obtain information and application forms from Dr. J. Coste, Laboratoire de Physique des Plasmas, Faculté des Sciences d'Orsay, Orsay, Seine-et-Oise, France.

OMNITAB

The increasing use of computers in scientific applications presents communication problems to the scientist not familiar with computer programing. As this problem grows, efforts are being made to provide the user with more convenient and efficient access to these machines. NBS, with its wide variety of data and small number of programers, is particularly plagued by this problem.

OMNITAB A Computer Program for Statistical and Numerical Analysis, NBS Handbook 101 ($3.00), written by J. Hilsenrath, G. G. Ziegler, C. G. Messina, P. J. Walsh, and R. J. Herbold, represents NBS efforts to alleviate the situation through a general-purpose digital computer program which permits users to communicate with a large computer by means of simple English sentences.

This volume, essentially a user's manual, discusses the general philosophy and motivation for the program design and specific instructions on the application of the program to a variety of calculations arising in research and development establishments. It is arranged so that the nonprogramer need read only so far as serves his purpose, and includes suggestions for additional reading as he becomes more proficient or requires more complex computations. A large number of cross-referenced examples, and several tables of formulas, commands, and information storage locations also aid the novice.

COPPER WIRE TABLES

Copper Wire Tables, NBS Handbook 100 (50 cents), prepared by Committee B–1 (Electrical Conductors) of the American Society for Testing and Materials in collaboration with the NBS Office of Engineering Standards, is a revision of Circular 31, published in 1912 and revised in 1914 and 1956. This edition contains changes in the nominal diameters of gages 45 and smaller, and extends the tables to 56 gages, as established in 1961 by the ASTM Committee on Wires for Electrical Conductors.

Handbook 100 is more than a set of tables, however. It provides a historical introduction into the subject of wire gages and gives information on other factors concerning usage of copper wires. Standard characteristics of copper, including resistivity, conductivity, and density are discussed, as well as the mathematics of wire gage determinations and aspects of stranded wire sizing. The tables cover a wide area of data, such as various standard values for resistivity, reductions of observations to standard temperature, and many tables of gage number followed by pounds per 1,000 feet, ohms per pound at different temperature, cross section, etc.; many of these factors are repeated in metric equivalents. Each table is accompanied by an explanation of data or values used.

Publications noted in this column, unless otherwise stated, are available for the price indicated from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402; the Clearinghouse for Federal Scientific and Technical Information, Springfield, Va., 22151; or from local U.S. Department of Commerce Field Offices.

NATIONAL STANDARD NSRDS REFERENCE DATA SYSTEM

NEWS

Modified Tape-Recording Typewriter

The compilation of evaluated data on the thermodynamic properties is one of the more important of the activities currently under way in the National Standard Reference System. A focal point for this activity is the revision of NBS Circular 500, *Selected Values of Chemical Thermodynamic Properties,* now being carried out in the Physical Chemistry Division. More than 12 years have been spent in this lengthy and time-consuming task.

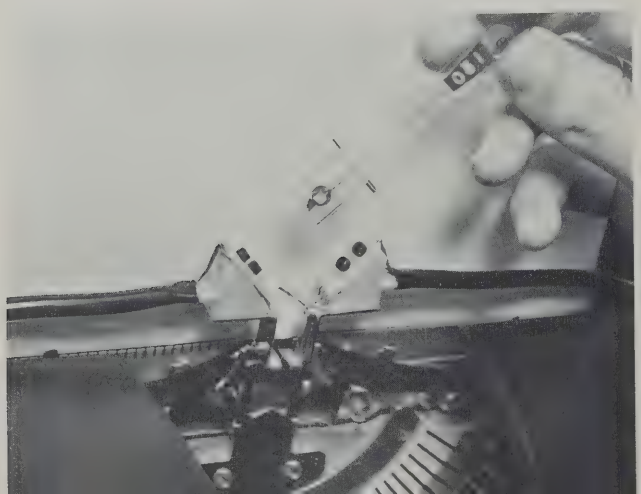
The time necessary to gather data and to critically evaluate them is difficult to shorten, but there has been a clear need to improve efficiency in proofing text and in producing a set of work cards preliminary to the actual compilation. To aid in this phase of the Circular's revision, the NBS Office of Standard Reference Data has had a modified tape-recording typewriter developed under contract. This device will be used to improve efficiency in text preparation, to assist in computer-generated photocomposition, and to produce the basic work cards by machine methods. It is also applicable to other compilation activities.

Besides automatically producing punched paper tape, the modified typewriter has the capability to provide coordinate positioning of each typed character on the page. In addition, the machine can automatically encode any one of approximately 90 selected (commercially available) auxiliary type faces inserted at the platen. This device has been named the "taxywriter" by the NBS staff to indicate a type face augmented X-Y recording typewriter.

The machine can operate either as a standard tape typewriter or in an augmented mode in which it produces four punched codes for each typed character. The four codes are those for the character, its X-coordinate, its Y-coordinate, and an item separator. Insertion of a modified type face element inactivates the standard coding for the typewriter keys; striking any key then produces on paper tape five codes, which are a type-face-element precedence followed by the auxiliary character, X- and Y-coordinates, and item separator. The modified type face element has four pin holes on each side, into which metal pins may be inserted to signify an 8-bit, odd-parity, binary code. The pins make electrical contact with a guide at the platen of the typewriter to activate the coding.

The modified typewriter is intended primarily as an input device, although it can be operated to produce output from paper tape in the auxiliary mode, as well as in the standard mode. In the auxiliary output mode, the machine stops when it senses augmentation precedence code, and displays by electronic readout the octal number for the type face character to be inserted. The use of this typewriter as an input device is intended to be in combination with a high-speed, extended-character printer operated from magnetic tape.

Left, pins inserted in the type face element complete an electrical circuit with the modified guide, producing a precedence code, type face code, X- and Y-coordinates, and a block separator for the inserted element—not for the key used. Right, Mrs. Sally Rice inserts a type face element into the modified guide on the tape typewriter. This NBS modification permits about 90 additional type face elements (partially hidden) to be used in the system. Besides the typewriter, the system consists of a reader (left), a readout device (foreground), and a printer (background). For each key, the system produces on paper tape a type face code, X- and Y-coordinates, and a block separator.



The Office of Standard Reference Data intends to use the new machine to prepare scientific text and tabular data. Any application in which superscripts, subscripts, special symbols, or coordinate-oriented material must be prepared in machine-sensible form could benefit from its use. Its principal advantages are:

(1) Immediate visual verification by the typist of the copy being produced.

(2) Rapidly prepared proof copy available on a day-to-day basis (as output from an extended character printer) for technical review.

(3) Daily editing on a line correction basis in conjunction with technical proofing.

(4) Availability of typewriter-quality scientific text with adequate symbols for preparation of manuscripts.

(5) Preparation of machine-sensible copy for use in producing publications by computer-generated photocomposition.

(6) Rapid, low-cost preparation of selected portions of recorded scientific text on cards or paper stock for manual filing.

The present machine is considered to be a prototype model subject to further modification. A second machine now being planned will have minor modifications that will speed the paper tape punch by 33 percent and will enable a punched record to be made of corrections to the copy.

American Chemical Society Survey

In August 1965, the American Chemical Society, on behalf of the Office of Standard Reference Data, sent a questionnaire to its members asking for information on their needs for compilations of critically evaluated data. Through this questionnaire the Office of Standard Reference Data learned a great deal about the needs of the chemical profession for data compilations; it also located a substantial number of compilation activities of which it was not aware. In addition, the Office identified dozens of individuals who are both interested and competent to undertake additional projects.

The questionnaire was mailed to about 100,000 ACS members. Approximately 16,000 replied, 12,000 of them within the first 6 weeks. About 2,000 respondents indicated that they were retired or were in a type of activity not requiring critically evaluated data. The results may be summarized as follows:

(1) An overwhelming number of respondents indicated that present compilations of data satisfy the data requirements of ACS members poorly or at best only moderately.

(2) About 300 data compilers previously unknown to the Office of Standard Reference Data were identified. A followup survey was sent to these 300 asking for further details of their data compilation work. This followup has revealed more than 30 compilers whose work is significant to the NSRDS program.

(3) The survey identified about 1,600 properties that ACS workers most often seek in the literautre. The responses also identified almost 1,000 properties which respondents believe are not at present adequately evaluated and compiled. The survey confirmed the judgments made by the Office of Standard Reference Data and its advisory committees regarding priorities in the program's compilation efforts.

(4) The survey identified those data compilations most often consulted by respondents. These comprise about 500 entries. The response revelaed that the Office of Standard Reference Data had acquired the majority of significant critically evaluated data compilations; it also identified a few sources that should be acquired.

(5) Many worthwhile comments and suggestions were received regarding priorities, approaches to take in compilations, and techniques of format and presentation.

Other Items of Interest

The sixth edition of Landolt-Bornstein volumes is included in the Office of Standard Reference Data's collection of data compilations. Translations of the prefaces and tables of contents of these volumes have been obtained and plans are being considered for making them available. As an aid to planning, the Office would appreciate expressions of interest in the availability of the translations.

The NBS Mass Spectrometry Data Center has prepared an up-to-date bibliography of all publications in the field of gaseous ion-molecule reactions. The bibliography includes approximately 500 references, both theoretical and experimental. It should be of interest to workers in atmospheric phenomena, radiation chemistry, and mass spectrometry. For further information, write Mr. F. N. Harllee, NBS Mass Spectrometry Data Center, National Bureau of Standards, Washington, D.C., 20234.

The members of the Computation Committee of the American Institute of Chemical Engineers have expressed considerable interest in having the data produced by various thermodynamic compilation groups stored on magnetic tape for use in process calculations. They say that the present generation of chemical engineers is being taught to use computers as freely as the previous generation used slide rules, and that therefore it is becoming increasingly important to have all data accessible from a magnetic memory bank. The Office of Standard Reference Data is exploring the feasibility of developing tapes from its associated data centers for such use.

A Symposium on Critical Data Evaluation Activities has been scheduled for September 12, 1966, as part of the New York meeting of the American Chemical Society. Dr. E. L. Brady, Chief of the Office of Standard Reference Data, is organizing the Symposium program for the ACS Division of Chemical Literature.

PUBLICATIONS

*of the National Bureau of Standards**

PERIODICALS

Technical News Bulletin, Volume **50,** No. 6, June 1966. 15 cents. Annual subscription: $1.50. 75 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

Journal of Research of the National Bureau of Standards

Section A. Physics and Chemistry. Issued six times a year. Annual subscription: Domestic, $5; foreign, $6. Single copy, $1.00.

Section B. Mathematics and Mathematical Physics. Issued quarterly. Annual subscription: Domestic, $2.25; foreign, $2.75. Single copy, 75 cents.

Section C. Engineering and Instrumentation. Issued quarterly. Annual subscription: Domestic, $2.75; foreign, $3.50. Single copy, 75 cents.

CURRENT ISSUES OF THE JOURNAL OF RESEARCH

J. Res. NBS 70A (Phys. and Chem.), No. 4 (July–Aug. 1966), $1.00.

Elastic constants of synthetic single crystal corundum. W. E. Tefft.

Phase equilibria as related to crystal structure in the system niobium pentoxide-tungsten trioxide. R. S. Roth and J. L. Waring.

Properties of aqueous mixtures of pure salts. Thermodynamics of the ternary system: water-calcium chloride-magnesium chloride at 25 °C. R. A. Robinson and V. E. Bower.

Properties of aqueous mixtures of pure salts. Thermodynamics of the ternary system: water-sodium chloride-calcium chloride at 25 °C. R. A. Robinson and V. E. Bower.

Use of the consistency check in the vector verification method. A. D. Mighell, B. T. Gorres, and R. A. Jacobson.

Self-reversal in the spectral lines of uranium. D. D. Laun.

Oscillator strengths for ultraviolet lines of Fe I. C. H. Corliss and B. Warner.

OTHER NBS PUBLICATIONS

NBS standard frequency and time services, NBS Misc. Publ. 236, 1966 edition (1966). 15 cents. (Supersedes previous editions.)

Statistical association methods for mechanized documentation. Symposium Proceedings Washington 1964, M. E. Stevens, V. E. Giuliano, and L. B. Heilprin, NBS Misc. Publ. 269 (Dec. 15, 1965). $2.75.

Report of the 50th national conference on weights and measures 1965, NBS Misc. Publ. 272 (Apr. 1, 1966). $1.00.

Photonuclear data index, NBS Misc. Publ. 277 (Apr. 1, 1966). 55 cents.

Bibliography on atomic transition probabilities, B. W. Glennon and W. L. Wiese, NBS Misc. Publ. 278 (Apr. 22, 1966). 55 cents. (Supersedes Mono. 50.)

Doors as barriers to fire and smoke, H. Shoub and D. Gross, Bldg. Sci. Series 3 (Mar. 25, 1966). 15 cents.

Nuclear and radiation standards of importance to the National Atomic Energy Program, H. W. Koch, J. H. Donnert, W. W. Havens, Jr., G. L. Rogosa, and L. Rosen, NBS Tech. Note 283 (Mar. 31, 1966). 35 cents.

Disclosures on magnetic tape handler focus detector, multi-pen recorder, signal averaging filter, electrostatic RMS voltmeter, back-up ring for o-rings, and low temperature solid state thermometer, Ed. D. Robbins and A. J. Englert, NBS Tech. Note 287 (Apr. 8, 1966). 25 cents.

List of errata to accompany the first, second, and third printings of NBS Applied Mathematics Series 55, Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables, Ed. M. Abramowitz and I. A. Stegun (April 1966). This errata is free to holders of AMS55, upon request from the Publications Section, A617 Administration Building, National Bureau of Standards, Washington, D.C., 20234.

PUBLICATIONS IN OTHER JOURNALS

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